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THE ROLE OF THE REMOTELY AUGMENTED VEHICLE (RAV) LABORATORY IN FLIGHT RESEARCH

Dorothea Cohen*
and
Jeanette H. Le**
NASA Dryden Flight Research Facility
Edwards, California

Abstract

This paper presents an overview of the unique capabilities and historical significance of the Remotely Augmented Vehicle (RAV) Laboratory at the NASA Dryden Flight Research Facility. The report reviews the role of the RAV Laboratory in enhancing flight test programs and efficient testing of new aircraft control laws. The history of the RAV Laboratory is discussed with a sample of its application using the X-29 aircraft. The RAV Laboratory allows for closed- or open-loop augmentation of the research aircraft while in flight using ground-based, high performance real-time computers. Telemetry systems transfer sensor and control data between the ground and the aircraft. The RAV capability provides for enhanced computational power, improved flight data quality, and alternate methods for the testing of control system concepts. The Laboratory is easily reconfigured to reflect changes within a flight program and can be adapted to new flight programs.

Nomenclature

ASCII	American Standard Code for Information Interchange
CADRE	cooperative advanced research experiment
CL	control law
CRT	cathode-ray tube
FSW	forward-swept wing
HiMAT	highly maneuverable aircraft technology
JSC	Johnson Space Center
PCM	pulse code modulated
RAV	remotely augmented vehicle
RAVES	Remotely Augmented Vehicle Expert System
RCD	remotely computed display
RPV	remotely piloted vehicle
SRV	spin research vehicle
TACT	transonic aircraft technology
WATR	Western Aeronautical Test Range

*Electronics Engineer.
**Aerospace Engineer.

Introduction

The NASA Dryden Flight Research Facility (Dryden) strives to enhance its flight test programs by providing superior data and testing new control law concepts safely and economically with high-quality results. Accomplishing these objectives efficiently calls for minimal flight hardware and software modifications and the use of computational power available from state-of-the-art ground-based computers.

In response to these needs, the Remotely Augmented Vehicle (RAV) Laboratory evolved to support flight test programs at Dryden. The RAV Laboratory's capabilities encompass three main areas: (1) research with a remotely piloted vehicle (RPV), (2) research with a RAV, and (3) remotely computed displays (RCDs) (Fig. 1). These remote computation techniques help reduce the time and cost necessary to complete a desired flight mission and improve the quality of flight research data.

Research with RPVs may be necessary due to flight safety reasons, cost limitations, or unavailability of a man-rated aircraft. The control laws for RPVs can be implemented in either the ground or onboard control law (CL) computers with a cockpit in the RAV Laboratory. Pilot inputs from the cockpit are fed through the ground-based CL computers and the resulting outputs are uplinked to the aircraft to drive the flight control surfaces. When the control laws are implemented onboard the RPV, the pilot's commands are uplinked to the aircraft. The visual cues for the pilot on the ground are provided through the RAV cockpit instruments and cameras either onboard the RPV or from a chase plane.

Remotely augmented vehicles provide new methods of testing control law system concepts by implementing the new control laws on the ground-based computers for more computational capability. Onboard primary control laws are then remotely augmented by ground computers which uplink surface commands to add to existing pilot inputs. The RAV computers can also uplink frequency sweeps, step inputs, or other commands for cleaner data collection than conventional methods. Individual surfaces can also be driven with this technique, which may not be possible solely through conventional pilot inputs to the onboard control laws.

The ground-based computers provide trajectory guidance through RCDs. These RCD techniques let ground computers use downlinked aircraft parameters to calculate the errors between the actual and desired flight conditions; the pilot may not be able to mentally compute such errors based on conventional flight instruments. These ground-computed directional cues are uplinked to a cockpit display to decrease the pilot workload required to achieve a desired flight condition. In some instances, RCDs make it possible to achieve flight profiles that could not have been attained by other means.[1]

History of the Remotely Augmented Vehicle Laboratory

The current RAV Laboratory capabilities have evolved beyond those of its predecessor, the Remotely Piloted Research Vehicle Facility created in 1971. In 1983, the Facility was combined with the Simulation Facility and incorporated remotely computed display techniques to form the Simulation/Remotely Controlled Vehicle and Display Laboratory. Presently, it is called the RAV Laboratory and it encompasses remote augmentation capabilities, whether open- or closed-loop, developed for a test vehicle.

The technology for remote control, augmentation, and displays were derived from programs like the F-15 spin research vehicle (SRV), the F-8 cooperative advanced research experiment (CADRE), and the F-111 transonic aircraft technology (TACT). The RPV, RAV, and RCD capabilities have since been applied, individually and collectively, to other flight test programs as well.

The need for an RPV capability emerged from the F-15 SRV program which investigated stall and spin characteristics. Due to high cost and the risks involved with a full-scale flight vehicle program, the project was conducted with a remotely controlled 3/8-scale prototype of the aircraft. Both the primary and secondary flight controls and pilot inputs were implemented through the RAV Laboratory.[2]

The F-8 CADRE was a remotely augmented vehicle used to develop nonlinear pitch flight control algorithms. The CADRE used FORTRAN control laws implementation by ground-based computers to avoid additions of onboard systems for the task. Also, since the control law algorithms were selected without previous pilot knowledge and initiated from the ground, the pilot evaluation of aircraft handling qualities was not biased.[3,4]

The F-111 TACT, designed with a supercritical wing for transonic maneuvers, was the first flight program to experiment with the remotely computed displays concept. Ground computers calculated the necessary trajectory correction based on downlinked flight data. This correction was uplinked to the aircraft to help the pilot accomplish the desired maneuvers. Better quality data were obtained with less time and cost.

Since these initial programs, the RAV Laboratory capabilities have been used in other flight test programs. The RPV techniques have been used in the highly maneuverable aircraft technology(HiMAT) program and the B-720 controlled impact demonstration, among others. Research vehicles like the X-29 forward-swept wing (FSW), the F-111 mission adaptive wing, and the F-18 high angle-of-attack research vehicle used RAV capabilities. These programs, along with others such as the F-15 highly integrated digital electronic control and the F-104 aircraft, also used RCD capabilities to help carry out their respective research.[1,5,6,7]

Remotely Augmented Vehicle Laboratory System in Flight Testing

The RAV Laboratory's role in flight testing is to support any flight test mission that requires closed-loop remote augmentation capabilities such as RAV and RPV applications, or open-loop capabilities as demonstrated in the use of RCDs (Fig. 2). The Laboratory provides the ground-based computational power necessary for remotely augmented vehicle missions. The RAV Laboratory is also equipped with its own raw data processing and flight monitoring capabilities.

The RAV Laboratory interfaces with other Dryden flight test facilities to accomplish its missions. The downlink signal is received from the Western Aeronautical Test Range (WATR), and the Laboratory sends back to the WATR the uplink parameters to be transmitted to the test aircraft (Fig. 3). The RAV Laboratory provides WATR with the processed downlink data and the calculated control law parameters for real-time recording. The Laboratory also interacts with the Dryden Mission Control Center, a facility within WATR which manages communication, conducts real-time analyses, and produces displays for flight safety.

Laboratory Hardware Description

The RAV Laboratory computer components include a data processing computer, a CL computer, and an expert flight monitoring system. Local recording hardware includes tape drives, printers, and strip charts (Fig. 3). A

MIL-STD-1553B bus control unit distributes data throughout the RAV Laboratory, while an uplink encoder and downlink driver permit access to WATR.

The RAV Laboratory uses two Encore 32/6750 (Encore, Fort Lauderdale, Florida) real-time computers with shared memory to handle the pulse code modulated (PCM) data processing and CL computations. These computers receive downlink telemetry from the aircraft through the WATR. The PCM computer converts raw parameter data into engineering units and exchanges the data with the CL computer through shared memory. The PCM computer also sends raw data to the monitoring terminals and the Remotely Augmented Vehicle Expert System (RAVES). These computers also have direct lines to the magnetic tape drive and a printer.

The MIL-STD-1553B bus is linked to the Encore shared memory region by a bus control/remote terminal unit and distributes the processed data to the expert monitoring system, strip charts, uplink encoder, and data formatter. Uplink data are sent from the uplink encoder through WATR transmitters to the test aircraft. Downlink data from the PCM computer and CL-computed parameters are sent through the data formatter to WATR to be recorded. Communication with both the pilot and other flight personnel is possible through a radio network handled through Mission Control.

The RAVES is interfaced to the 1553 bus by way of a decommutation system. The decommutation system monitors the raw PCM data stream and the 1553 bus to provide RAVES with the necessary flight and synchronization data for telemetry monitoring. The decommutation system also provides limited mathematical capability for the preprocessing of data for RAVES. The workstation can command the decommutation system using a serial port link.

Pulse Code Modulated and Control Law Software

The PCM software is designed to decommutate and calibrate downlink and uplink flight data, while the CL software calculates the control law algorithms or supplementary guidance systems to implement on the research aircraft. Each software is built from a generic skeleton that can be specifically reconfigured to operate with a specific flight program. The code structure includes a background task that does initialization and dynamically updates the cathode-ray tube (CRT) display pages on a time-available basis. These display pages output parameter information to give the operator a way of interfacing with the software systems. Each software also manages an interrupt-driven real-time loop which carries out the higher priority real-time tasks.[8]

The PCM real-time tasks include synchronization checks, parameter decommutation and calibration, downlink discrete processing, and outputting of uplink parameters (Fig. 4). The CL real-time loop inputs the downlink parameters and executes the necessary front-end calculations, validity tests, and mission-specific tasks such as guidance needle calculations or control surface inputs (Fig. 5).

For flight programs that require RAV capabilities, the desired downlink or uplink parameters are pre-specified. The PCM computer extracts these parameters from the frames of data telemetered between the test aircraft and the ground.

Information necessary to decommutate and calibrate these specified parameters are contained in an input file which is read by the PCM software during initialization. This file is generated for each flight program and is updated and re-released to accommodate changes. The instructions for each parameter include the parameter name, sampling rate, frame of data where it first appears, word position within the frames, and buffer destination. For the calibration, the PCM software also requires the type of parameter (uplink or downlink), method of calibration to be conducted (curve fit or tabular), and corresponding calibration scaling.

Discretes require no calibration and are loaded into a discrete buffer to be processed and sent to the CL computer as an integer array. The PCM computer also receives radar data from the WATR which are converted to integer format in a separate interrupt-driven loop.

The CL software ground-computes the alternate control law algorithms implemented for the test aircraft. For RAV research, the CL computer can calculate pre-determined surface commands such as frequency sweeps, pulses, or individual surface deflections to add onto the existing pilot inputs. For RPVs, the CL computer handles the control laws for the aircraft as it is piloted from the ground and uplinks the output commands to drive the corresponding onboard control surfaces. For RCDs, the CL software determines differences between desired flight conditions and the actual conditions from the downlinked flight data. These differences are then uplinked and displayed onboard the test aircraft.

The PCM and CL computers perform real-time tests to track the data transfer status between the aircraft, the RAV Laboratory, and other systems in the loop. Each computer observes the execution status of the other system, performs data synchronization checks, and monitors data transfer failures between the two computers.

The PCM computer passes its interrupt counter through shared memory to the CL computer to indicate whether or not its real-time loop is still executing. Should the PCM fail, flags will be set in shared memory and subsequently sent to the uplink encoder to inform the aircraft of its downlink and uplink status with the RAV Laboratory. Likewise, the PCM computer can monitor the CL real-time loop counter which is placed in shared memory.

Synchronization checks determine if the PCM computer is in sync with the PCM data stream. If the sync fails, the downlink data stream processing is bypassed and a flag signals the aircraft and the CL computer of the situation.

The PCM computer also performs window tests and limit checks on the incoming data to ensure that the data do not fall outside the specified range.

Other tests that are conducted by the CL software include wraparound tests, pilot override, radar sync, and any maneuver/mode/limits/reasonableness tests that vary with the flight mission. These validity tests are conducted before the calculated outputs from the CL computer are placed in shared memory.

All RAV software is validated to confirm that the software meets its specification, and verifications are conducted to show that the software running is the correct version. Software validation for the PCM software can be done with the use of pre-recorded flight data (in the case of an existing flight program), actual flight data, or other ways of generating an input PCM stream such as a PCM formatter to provide "artificial" downlink data. The downlink data are fed into the PCM software that carries through the conversions. Data output from the PCM software are then monitored from the CRT display pages. The CL software is validated by interfacing with a real-time simulation of the aircraft. Combined systems tests are conducted, incorporating all of the hardware into the loop with the aircraft on the ground. Once validated and released for use, the software is then verified by check sums produced by a cataloger and bit comparisons to the same program on a tape.

A section of pre-flight checks is also dedicated to verification of RAV operations. These checks ensure that the aircraft link to RAV is operational, that the RAV laboratory is sending and receiving commands, and that the pilot can disengage RAV if necessary.

Remotely Augmented Vehicle Expert System Software

The RAVES in the RAV Laboratory was designed to make the monitoring of RAV flights easier. The system gives the operator more effective displays using color thresholds, graphical representations of aircraft systems, and other visual cues. Before RAVES, the displays used for flight monitoring in the RAV Laboratory were limited to black and white CRT displays with ASCII outputs and no mouse control. Newer technology has upgraded the monitoring capabilities of criticalparameters in the Laboratory by providing color graphics and mouse capabilities to improve human-computer interface (Fig. 6).[9]

The RAVES is based upon the Johnson Space Center's (JSC's) Real-Time Display System, a C-language program that supports the space shuttle.[10] Benefits arise from using the JSC software because (1) concurrent developments by NASA, JSC, and the Air Force can be shared to improve the system, (2) a large base of users is already associated with the software, and (3) the collective effort fosters collaboration among the government branches. The programming methodology of the data acquisition, a round robin-style ring, is taken from JSC's program, along with some of the graphics for monitoring the data acquisition. The actual data acquisition is through a decommutation system with the ability to monitor the raw PCM and 1553B bus.

The RAVES display graphics for flight parameter monitoring uses DataViews®, a generic graphics package. DataViews® includes two packages: DVDraw®, an interactive drawing package that allows for dynamics; and DVTools®, the programming graphics language. DVDraw® lets users design new displays without the demand for coding by a programmer. Modifications of an existing display or creation of a new display can then be quickly done without recompiling the RAVES software.

The RAVES has four major display features: a monitoring window, a status line, a fault message window, and an expert system interface. The primary window displays user-designed pages that monitor flight parameters. The status line shows the current flight number, date, time, and data acquisition status. The fault message window has time-tagged and color-coded messages that are also logged to a file. The expert system includes notification of a dangerous or unusual occurrence within the fault message. Also, as an optional feature, the system lists appropriate actions to take in a popup window.

The RAVES uses a standardized color-coding technique to indicate status for critical and noncritical parameters as well as selection modes for various features (Fig. 7). Colors let the monitoring engineer quickly note flight status. This standardization also lets engineers go from project to project with the same color scheme, thereby lowering the learning curve on a new project.

The RAVES also has a local data-logging feature. This feature, if enabled, allows RAVES to continuously take data received and write it to a round robin file. When an interesting condition occurs, the user can tell RAVES to save the current contents of the round robin file to a permanent log file of selectable size. In addition to this log file, RAVES also creates three files containing the time of the save, parameters accessed by direct memory, and corresponding fault messages. Up to 10 unique sets of log files can be saved for each run of RAVES.

Tests are conducted for RAVES to verify the calculation algorithm for each parameter, the fault messages, the parameter limits, all changes of color, the changes of sign, and the expert system messages. This series of tests follows on the completion of PCM and CL verification and validation.

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Laboratory Application in Flight Testing: The X-29 Flight Program

The X-29 FSW program, a study of new flight control laws and aerodynamic concepts, relied on the RAV Laboratory's abilities to remotely augment vehicle configurations and uplink remotely computed displays. The RAV Laboratory's computers provided a series of guidance parameters for an onboard RAV pilot steering system to help the pilot achieve desired flight maneuvers and control. The RAV systems also added pre-calculated control surface and stick or pedal commands to the existing pilot inputs for studies in aircraft flight responses.

When assisting the pilot in the guidance task, the CL computer compared the actual flight data to a reference flight profile as selected by the ground operator. The CL computer then calculated the differences and uplinked them to a set of vertical, horizontal, and Mach guidance needles onboard the aircraft to cue the pilot.

The CL computer also generated a series of pre-set input commands for uplink to the aircraft control surfaces, pitch or roll stick and directional pedal. The X-29 program must be able to run a series of different step inputs sequentially to the same or different surface or pilot command. These step inputs can be selected by the ground operator from a CRT menu of pre-calculated and pre-tested step inputs once RAV has been enabled by the pilot. Similarly, frequency sweeps can either be initiated by the ground operator or engaged by the pilot. Such ground-computed inputs are added to the existing pilot commands and therefore the pilot is never removed from the loop. These remote inputs also give cleaner flight data results.

The RAVES was first used during the X-29 flight test program to monitor the RAV operations. Engineers were able to detect RAV operation failures more quickly with the program's graphics capabilities. The RAVES also offered a practical local recording technique in its logging feature.

The most pronounced benefit of RAVES is in the speed at which the engineer can see, and therefore react to, a failure. Before RAVES, a failure could be noted in two ways: by a light-emitting diode light on a control panel, or by a logical discrete (true or false) on an ASCII display. The RAVES offers two alternate methods to quickly recognize failures: a color change on the display, or a notice posted in the fault message window. For example, RAVES signaled a RAV command uplink failure by changing the color of the parameter from green to redand outputting a red fault message. In another instance, the incorrect radar switch feed was discovered through fault messages.

The RAVES logging feature allows quick access to critical flight segments to help determine what may have occurred during the flight. Also, logging allows data files to be saved and replayed without the need of a flight tape and having the entire laboratory operational. In one instance, a flight was aborted because of failures to maintain RAV communications with the X-29 test aircraft. A log made during flight was replayed through RAVES, requiring only the presence of the RAVES workstation where the data file resides. The cause for failure was easily detected and flight resumed the following day.

The RAV capabilities provided the X-29 program with a way to accomplish missions which may not have been conceivable otherwise. Manipulation of individual surfaces, for instance, would not have been possible solely through pilot inputs because the primary control laws move multiple surfaces simultaneously. Cleaner aircraft responses were also obtained through the ground-computed inputs. Also, the steering guidance cues gave pilots an easier and faster way of accomplishing the desired flight profiles. The RAV systems provide for efficient flight test operations and high-quality research data at the lowest possible costs.

Systems Development, Adaptation, and Integration for New Flight Programs

Adapting RAV operations to a new flight test program requires both software and hardware modifications to reflect the aircraft and its mission. Because the foundation for the RAV software packages are already established, any changes need only reflect those required by the flight test program. Hardware modifications are necessary for the aircraft to accommodate basic RAV operations, with more extensive ground hardware modifications necessary for RPV purposes.

Modifications of data processing information necessary for the PCM software are required for the flight program's specific needs. The PCM software engineer regenerates the data file that contains the instructions for decommutation and calibration of each flight parameter to include instructions for the new research program. Validation tests are again conducted to assure "flight-readiness" of the software for actual flight operations.

The CL software modifications may be more extensive and are highly dependent on the flight test objectives. Although the skeleton of the CL software remains the same, new front-end calculations are implemented to accommodate RPV, RAV, or RCD applications. The CL software can emulate the control system, be a separate system with augmentation, or take the downlinked onboard outputs, process them, and then send them back to the plane (bypassing the onboard system). Validation for this software is primarily done through the simulation and is further checked along with the PCM software during the combined systems tests.

There are three major efforts needed to add a new flight program module to RAVES: reprogramming the decommutation system, designing new displays, and calculating any parameters specific to the flight program. Once these are completed, it is only necessary to test and verify the accuracy of the displays and parameters.

The RAVES displays can be designed by a project engineer on any workstation running DVDraw®. The decommutation system requires programming of the parameter list, which can be saved to diskette. A programmer takes the designed displays and parameter release documents for the project to devise the main menu display and code parameter calculation with appropriate messages. Once the updates are completed, the programmer and other engineers on the project will decide if there are any unusual conditions or sets of conditions to beware of. This knowledge is then integrated into the expert interface and fault message window.

Onboard software modifications are program dependent. The software hooks for RCD, RAV, and RPV applications must be added to remotely drive the vehicle instruments and surfaces. In RCD, the software is modified to take the uplink signal and display it on an instrument as a "fly-to" indicator. For RAV and research with RPV, the onboard CL software is adjusted to take the uplink and conduct scalings, limit checks, and error detections before applying the signal to the surface. There also is a provision in a piloted RAV for an automatic and pilot disengage of RAV Laboratory commands.

Remotely piloted vehicle operation will also need additional ground hardware to provide redundancy as well as a ground station for remote piloting. The redundant system consists of an additional set of PCM/CL stations and computers that serve as the standby system if the active computers fail. The pilot station usually consists of a cockpit with full instrumentation and video equipment for additional visual support. The stick computer allows selection of the stick and rudder characteristics and provides the interface between the pilot's controls and the CL computers.

Hardware modifications onboard the test aircraft are necessary for all RCD, RPV, and RAV applications. For any application by the RAV Laboratory, a dedicated receiver is installed on the aircraft to acquire the uplink signal. Sometimes a frequency (diversity) combiner is used to maintain blanket coverage for continuous uplink contact with the aircraft.

Modification for use of RCD involves using the uplink to drive displays onboard the aircraft. The output of the uplink on the aircraft is tied to a display device on the aircraft. This device may be a pre-existing onboard instrument or the aircraft may require the installation of a new display mechanism.

For RAV missions, the output of the uplink is fed into either an autopilot or the control system. Hardware provisions are needed to receive and feed these commands into the control system. Hardware and software systems checks ensure control and flight safety.

Aircraft modifications for RPV operation are similar to those in RAV operation. In RPV applications, the combiner is always used and there are more systems checks in both the hardware and software to ensure control and safety. The RPV operation has a ground-based backup system in case of a failure in the primary system. Visual cues are provided by cockpit instruments and the camera onboard the RPV or the chase plane. A backup system can also be placed onboard the RPV in case the uplink signal from the ground is lost. This onboard backup can be controlled from a chase aircraft which allows the chase pilot to land the RPV or direct it away from any populated area. If both systems are employed, the control authority can be switched between the ground or the chase plane backup system, as required.

Future Applications and Expansion of Capabilities for RAV

Other applications and expansions of RAV capabilities are continually being explored. Currently, computer graphics is being examined.

Aside from computer visuals, which only indicate aircraft trajectories on a map, new 3-D computer graphics showing an aircraft model and its flight attitudes have been designed and interfaced with ground simulations (Fig. 8). These visualization capabilities are easily transferable to the RAV Laboratory. The RAV data can be routed to the 3-D visual system to show the aircraft's motions during flight.

The future for RAVES includes the making of displays on-the-fly and an X-window interface. These capabilities are available in another package using the same graphics and operating in conjunction with the current Dryden simulations.

Also, two-way communication and control, currently supplied by the CL displays, can also be developed for the RAVES workstation by way of the decommutation system. This capability would allow users to command as well as monitor flights from RAVES.

Concluding Remarks

The Remotely Augmented Vehicle Laboratory at the NASA Dryden Flight Research Facility is unique in its ability to offer remotely piloted vehicle, remotely augmented vehicle, and remotely computed display capabilities in a single facility. These capabilities have helped the Facility to efficiently conduct its flight test programs, to provide better quality data, and to conduct tests that may not have been possible otherwise.

The ground-based computers in the Remotely Augmented Vehicle Laboratory add computational power and minimize the aircraft software and hardware modifications

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required for flight testing of a research vehicle. Remotely piloted vehicle technology has allowed flight testing on vehicles such as the highly maneuverable aircraft technology vehicle where advanced aircraft systems required unmanned operations. Remote augmentation of vehicles offers a rapid method to test alternative control law concepts. Remotely computed displays have proven invaluable by assisting the pilot in performing difficult flight test maneuvers.

The wealth of past flight test experience with the Remotely Augmented Vehicle Laboratory has demonstrated the Laboratory's ability to quickly accommodate new research programs with a minimum of time and effort.

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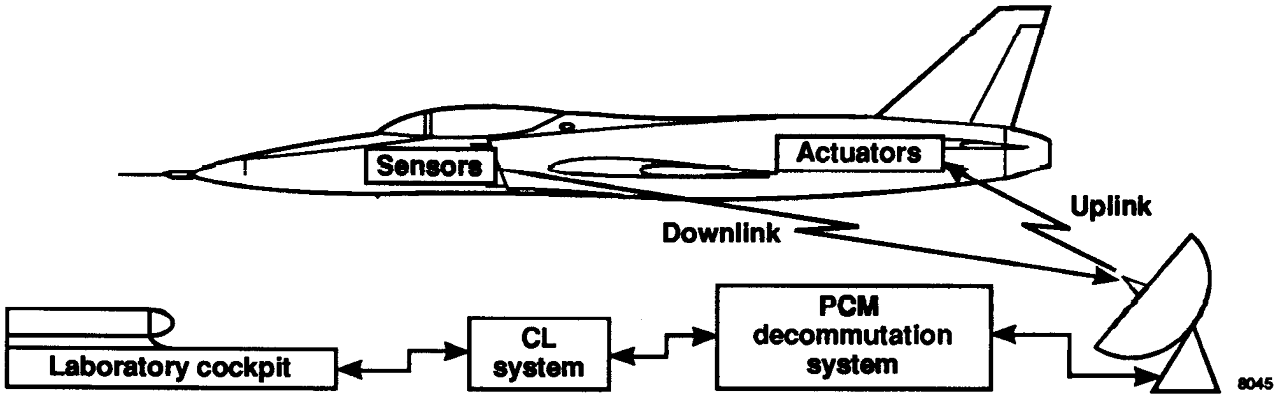
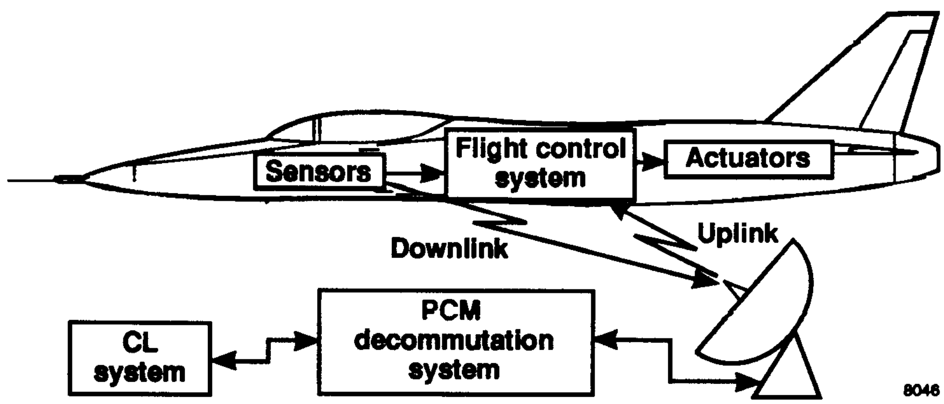
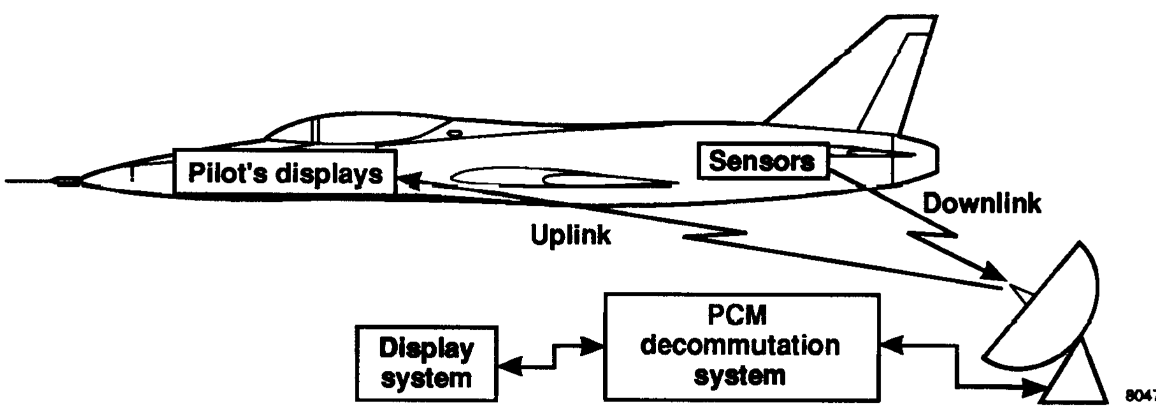


(a) Remotely piloted vehicle.



(b) Remotely augmented vehicle.



(c) Remotely computed display.

Fig. 1. RAV configurations.

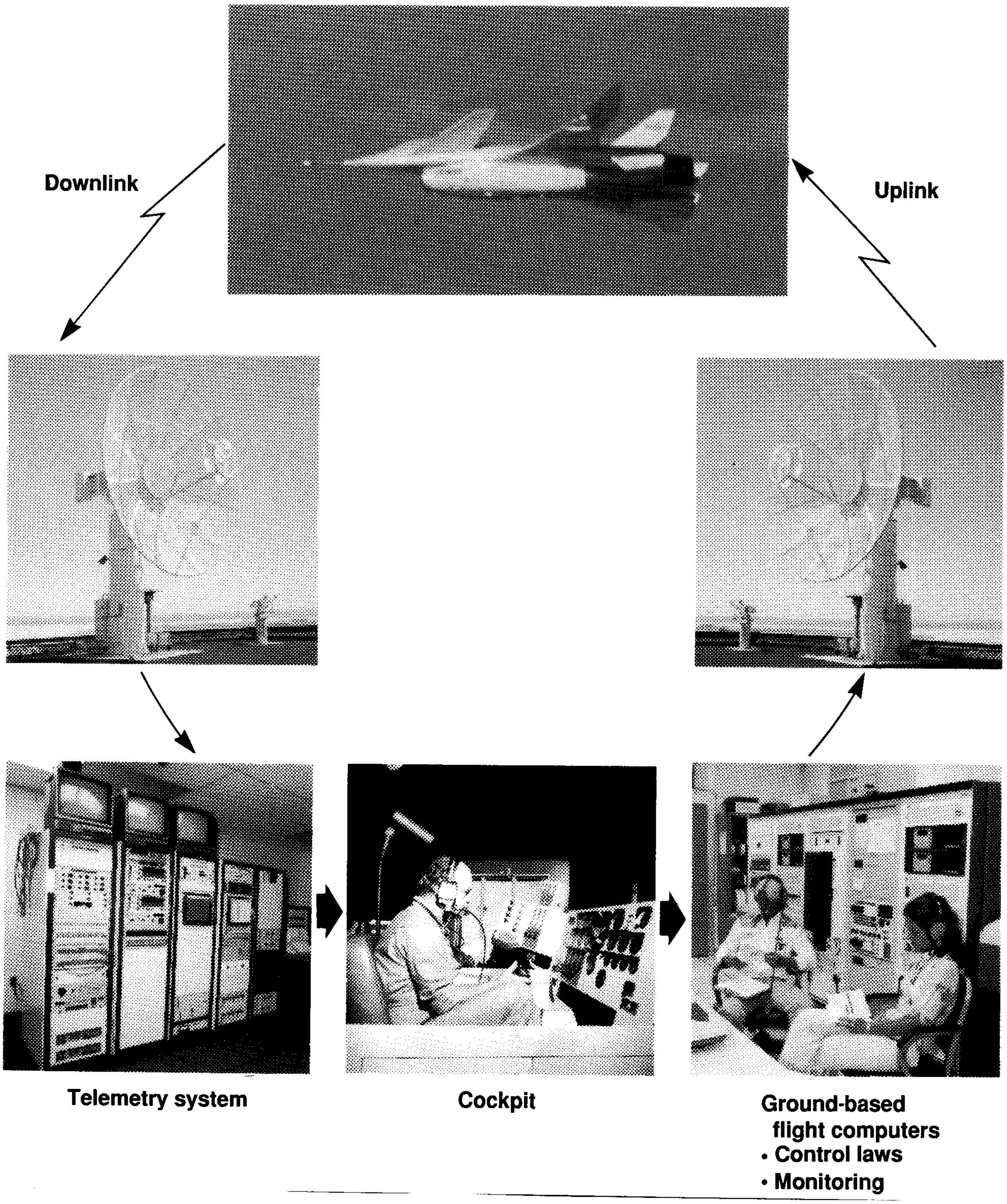


Fig. 2. RAV laboratory elements.

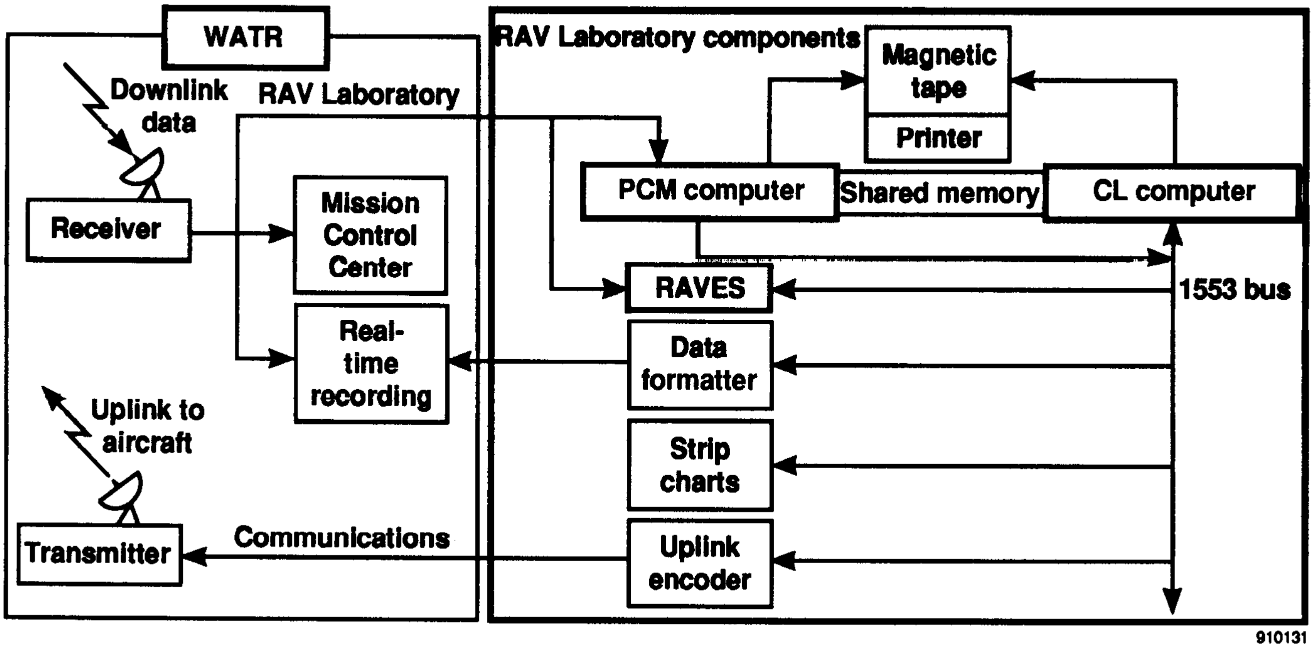


Fig. 3. RAV Laboratory block diagram.

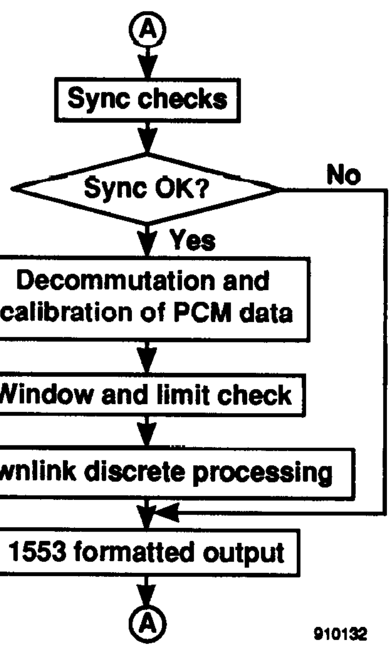


Fig. 4. PCM software structure.

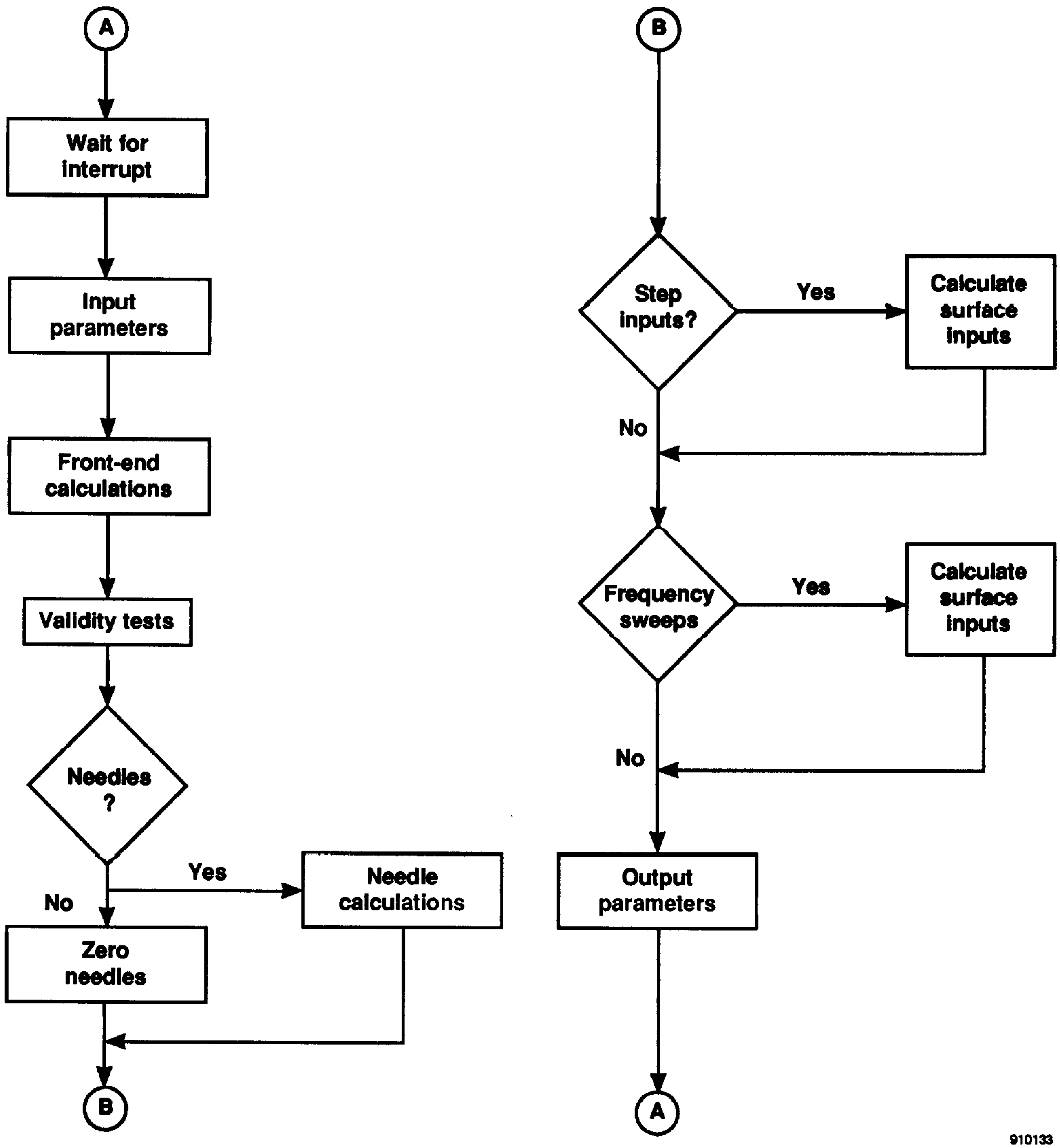


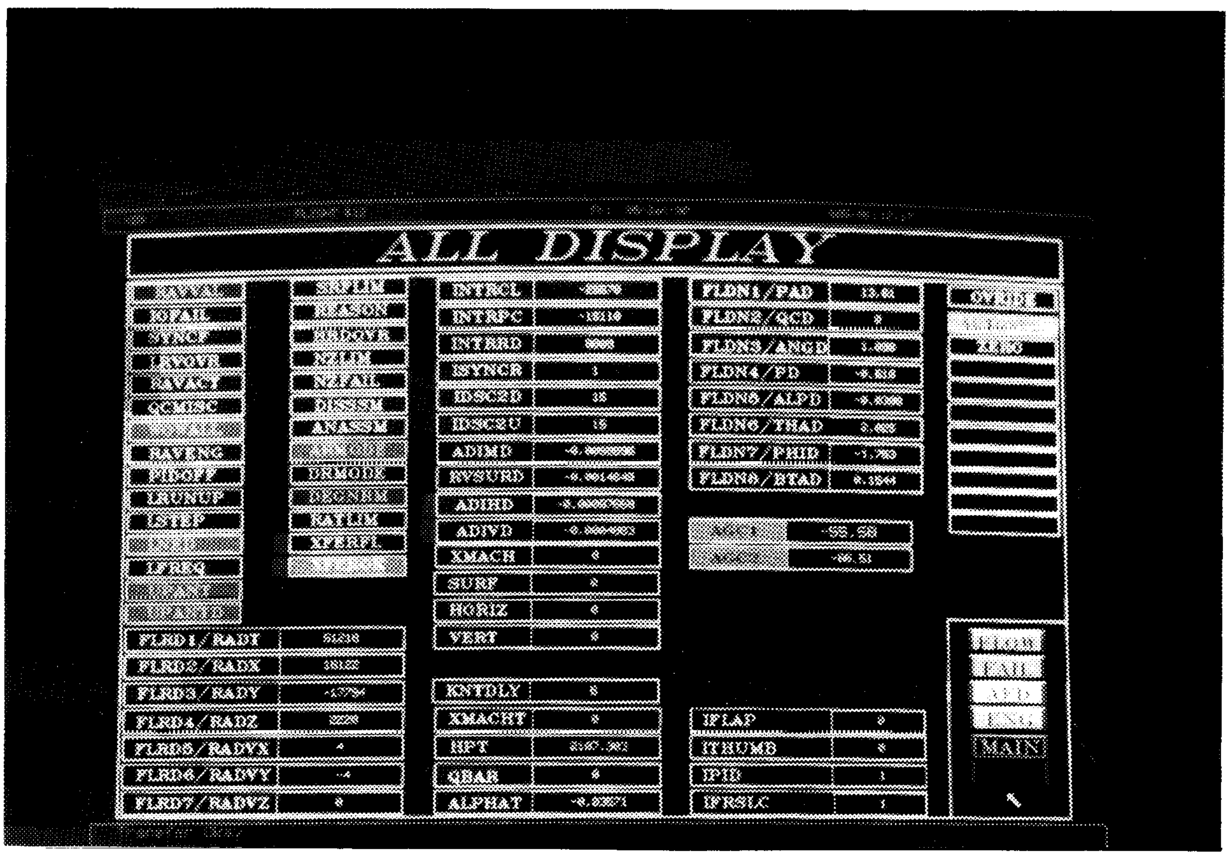
Fig. 5. CL software structure for full RAV application.

```
                                  ALL  DISPLAY

FSW RAV FLIGHT RAVVAL: T  5 ZERØ ALL GAINS        REV: RAV00004  15:08:41

    INTRCL             0 CALCULATED VALUES        F SRFLIM F   LNED    T
  F INTRPC             0   F HPT       ,0000E+00  F REASØN F   LSTEP   F
  F INTRRD             0     XMACHT    ,0000E+00  F HRDØVR F   LFREG   F
  F ISYNCR             0     GBAR      ,0000E+00  F NZLIM  F   LRUNUP  F
  F IDSC2D     0000          ALPHAT    ,0000E+00  F NZFAIL F
    IDSC2U     0000          KNTDLY            0  F DISSSM F
DØWNLINK DATA                                     F ANASSM F
1 F PAD        ,0000E+00                            SYNCF  F
2 F GCD        ,0000E+00 RADAR DATA               F ARMØCE F
3 F ANZD       ,0000E+00 1 F RADT      ,0000E+00  F DRMØCE F
4 F PD         ,0000E+00 2 F RADX      ,0000E+00  F DEGNRM F
5 F ALPD       ,0000E+00 3 F RADY      ,0000E+00  F RATLIM F
6 F THAD       ,0000E+00 4 F RADZ      ,0000E+00    IØFAIL F
7 F PHID       ,0000E+00 5 F RADVX     ,0000E+00  F XFERØK F
8 F BTAD       ,0000E+00 6 F RADVY     ,0000E+00  F XFERFL F
9   ADIMD      ,0000E+00 7 F RADVZ     ,0000E+00    LRVØVR F
10  RVSURD     ,0000E+00 OPLINK DATA                RAVACT F
11  ADIHD      ,0000E+00 1 F XMACH     ,0000E+00    RAVVAL T
12  ADIVD      ,0000E+00 2 F SURF      ,3688E-39    WØWALL F
13  AGC1       ,0000E+00 3 F HØRIZ     ,0000E+00    PIDØFF F
14  AGC2       ,0000E+00 4 F VERT      ,0000E+00    RAVENG F
```

(a) Control law display in standard black and white ASCII format.



EC90 0010-006

(b) RAVES display.

Fig. 6. RAVES display in contrast to a CL display page.

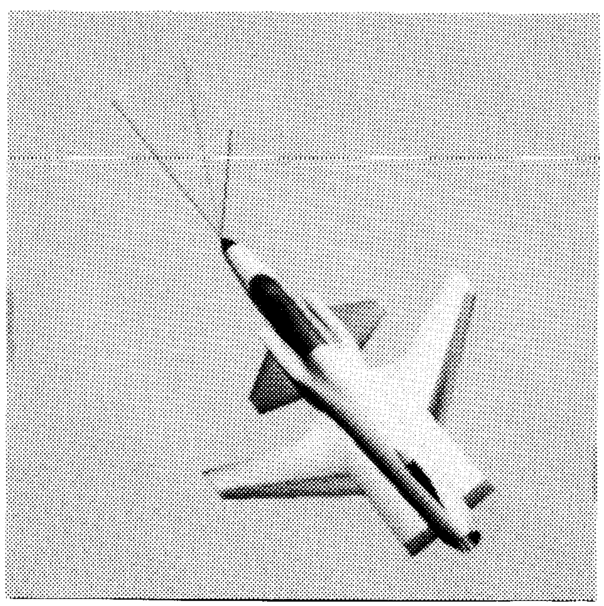
Status \ Parameter type	*Critical*	*Noncritical*
OK	GREEN	BLACK
Failing	YELLOW	YELLOW
Failed	RED	RED

(a) Designated colors highlighting critical and noncritical flight parameters based on status.

Mode	*Selected*	*Not selected*
Color	BLUE	BLACK

(b) Color scheme used for flight modes showing selection status.

Fig. 7. RAVES color-coding scheme.



EC90 0084-2

Fig. 8. Computer-generated 3-D model of the X-29A aircraft showing its flight attitudes.

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Dorothea Cohen and Jeanette H. Le

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13. ABSTRACT *(Maximum 200 words)*

This paper presents an overview of the unique capabilities and historical significance of the Remotely Augmented Vehicle (RAV) Laboratory at the NASA Dryden Flight Research Facility. The report reviews the role of the RAV Laboratory in enhancing flight test programs and efficient testing of new aircraft control laws. The history of the RAV Laboratory is discussed with a sample of its application using the X-29 aircraft. The RAV Laboratory allows for closed- or open-loop augmentation of the research aircraft while in flight using ground-based, high performance real-time computers. Telemetry systems transfer sensor and control data between the ground and the aircraft. The RAV capability provides for enhanced computational power, improved flight data quality, and alternate methods for the testing of control system concepts. The Laboratory is easily reconfigured to reflect changes within a flight program and can be adapted to new flight programs.

14. SUBJECT TERMS

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